

MODELING OF 10 GEV-1 TEV LASER-PLASMA ACCELERATORS USING LORENTZ BOOSTED SIMULATIONS*

J.-L. Vay[†], C. G. R. Geddes, E. Esarey, W. Leemans, C. B. Schroeder, LBNL, USA
D. P. Grote, LLNL, USA
E. Cormier-Michel, Tech-X, USA

In a laser plasma accelerator, a laser pulse is propagated through a plasma, creating a wake of regions with very strong electric fields of alternating polarity [1]. An electron beam that is injected with the appropriate phase can thus be accelerated to high energy in a distance that is much shorter than with conventional acceleration techniques [2]. The simulation of a laser plasma acceleration stage from first principles using the Particle-In-Cell technique in the laboratory frame is very demanding computationally, as the evolution of micron-scale laser oscillations needs to be followed over millions of time steps as the laser pulse propagates through a meter-long plasma for a 10 GeV stage.

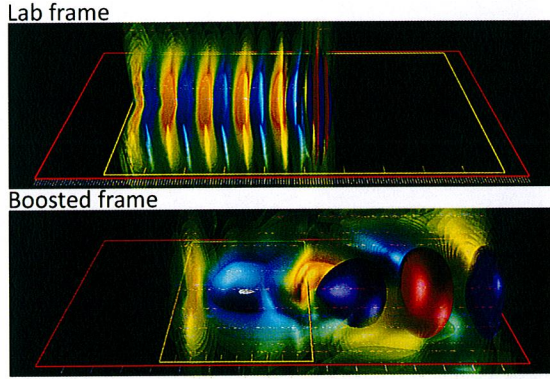


Figure 1: Simulations with the code Warp of scaled laser plasma acceleration stages: (top) in the lab; (bottom) in a Lorentz boosted frame (laser pulse in blue/red; plasma wakefield in pale blue/yellow).

A method was recently demonstrated to speed up full PIC simulations of a certain class of relativistic interactions by performing the calculation in a Lorentz boosted frame [3], taking advantage of the properties of space/time contraction and dilation of special relativity to render space and time scales (that are separated by orders of magnitude in the laboratory frame) commensurate in a Lorentz boosted frame, resulting in far fewer computer operations. As illustrated in Fig. 1, which shows snapshots from simulations of a sample LPA stage, in the laboratory frame the laser pulse is much shorter than the wake, whose wavelength is also much shorter than the acceleration distance ($\lambda_{laser} \ll \lambda_{wake} \ll \lambda_{acceleration}$). In a Lorentz boosted frame co-propagating with the laser at a speed near the

speed of light, the laser is Lorentz expanded (by a factor $(1 + v_f/c)\gamma_f$ where $\gamma_f = (1 - v_f^2/c^2)^{-1/2}$ and v_f is the velocity of the frame and c is the speed of light). The plasma (now moving opposite to the incoming laser at velocity $-v_f$) is Lorentz contracted (by a factor γ_f). In a boosted frame moving with the wake ($\gamma_f \approx \gamma_{wake}$), the laser wavelength, the wake and the acceleration length are now commensurate ($\lambda_{laser} < \lambda_{wake} \approx \lambda_{acceleration}$), leading to far fewer time steps by a factor $(1 + v_f/c)^2 \gamma_f^2$, hence computer operations [3, 4].

Recently, control of a violent numerical instability that limited early attempts [5, 6, 7] was obtained via the combination of: (i) the use of a tunable electromagnetic solver and an efficient wideband digital filtering method [8], (ii) observation of the benefits of hyperbolic rotation of space-time on the laser spectrum in boosted frame simulations [9], and (iii) identification of a special time step at which the growth rate of the instability is greatly reduced [8]. A novel numerical method for injecting the laser pulse through a moving planar antenna was also introduced [4]. The combination of these methods enabled the demonstration of a speedup of over a million times for the modeling of a hypothetical 1 TeV stage, and over 10,000 for a 10 GeV stage [9].

REFERENCES

- [1] T. Tajima, J. Dawson, Phys. Rev. Lett. 43 (4) (1979) 267–270.
- [2] W. P. Leemans, B. Nagler, A. J. Gonsalves, C. Toth, K. Nakamura, C. G. R. Geddes, E. Esarey, C. B. Schroeder, S. M. Hooker, Nature Phys. 2 (10) (2006) 696–699.
- [3] J.-L. Vay, Phys. Rev. Lett. 98 (13) (2007) 130405/1–4.
- [4] J.-L. Vay, C. G. R. Geddes, E. Esarey, C. B. Schroeder, W. P. Leemans, E. Cormier-Michel, D. P. Grote, Phys. Plasmas 18 (2012) 123103.
- [5] D. Bruhwiler, J. Cary, B. Cowan, K. Paul, C. Geddes, P. Mulowney, P. Messmer, E. Esarey, E. Cormier-Michel, W. Leemans, J.-L. Vay, AIP Conference Proceedings, Vol. 1086, 2009, pp. 29–37.
- [6] J.-L. Vay, W. M. Fawley, C. G. R. Geddes, E. Cormier-Michel, Proc. Particle Accelerator Conference, Vancouver, Canada, 2009, TU1PB104.
- [7] S. F. Martins, R. A. Fonseca, W. Lu, W. B. Mori, L. O. Silva, Nature Phys. 6 (4) (2010) 311–316.
- [8] J.-L. Vay, C. G. R. Geddes, E. Cormier-Michel, D. P. Grote, J. of Comput. Phys. 230 (15) (2011) 5908–5929.
- [9] J.-L. Vay, C. G. R. Geddes, E. Cormier-Michel, D. P. Grote, Phys. Plasmas 18 (3) (2011) 030701.

* Supported by the US-DOE under Contract DE-AC02-05CH1123 and the SciDAC/ComPASS project. Used resources of the National Energy Research Supercomputer Center (NERSC).

[†] jlvey@lbl.gov

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor The Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or The Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or The Regents of the University of California.